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I also certify that the application is now proceeding in the name as identified herein.

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Dated 25 March 2004

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GB0126014.0

By virtue of a direction given under Section 30 of the Patents Act 1977, the application is proceeding in the name of:-

GENTECH INVESTMENT GROUP AG
Incorporated in Switzerland
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ADP No. 08361271001

Patents Form 1/77
Patents Act 1977
(Rule 16)

The Patent Office

Request for grant of a patent

The Patent Office
Cardiff Road
Newport
South Wales NP10 8QQ

1. Your reference
   1864901/AM

2. Patent Application Number
   30 OCT 2001

3. **0126014.0** or of each applicant *(underline all surnames)*

   ... Technologies Limited
   Harston Mill
   Harston
   Cambridgeshire
   CB2 5GG

   SECTION 30 (1977 ACT) APPLICATION FILED 15.03.02

   Patents ADP number *(if known)* 7140601

   If the applicant is a corporate body, give the country/state of its incorporation — Country: **ENGLAND** State:

4. Title of the invention

   MODULATED FIELD POSITION SENSOR

5. Name of agent — **Beresford & Co**

   "Address for Service" in the United Kingdom to which all correspondence should be sent — **2/5 Warwick Court**, **High Holborn**, **London WC1R 5DH**

   Patents ADP number 1826001

6. Priority details

   Country | Priority application number | Date of filing

Patents Form 1/77

7. If this application is divided or otherwise derived from an earlier UK application give details

Number of earlier application | Date of filing

8. Is a statement of inventorship and or right to grant of a patent required in support of this request?

YES

9. Enter the number of sheets for any of the following items you are filing with this form.

Continuation sheets of this form

Description 5

Claim(s)

Abstract

Drawing(s)

10. If you are also filing any of the following, state how many against each item.

Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent *(Patents form 7/77)*

Request for preliminary examination and search *(Patents Form 9/77)*

Request for Substantive Examination *(Patents Form 10/77)*

Any other documents *(please specify)*

11. I/We request the grant of a patent on the basis of this application

Signature Beresford & Co
BERESFORD & Co

Date 30 October 2001

12. Name and daytime telephone number of person to contact in the United Kingdom

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Modulated field position sensor

Introduction

Inductive position sensors determine the position of a moveable target by measuring the inductive coupling between the target and one or more sensors. The target is often some form of dipole source, either powered directly or indirectly (e.g. inductively powered). The sensors are often coils, the geometry of which determines how their coupling to the target depends on the position of the target.

It is often advantageous to make a position measurement using more than one sensor, for various reasons:

- Ratiometric measurements can be made which eliminate the dependence on the absolute strength of the target;
- Measurements can be made at more than one spatial scale, e.g. coarse and fine measurements or vernier measurements, which allow the target position to be accurately determined over a long range of positions;
- The position of the target can be determined along more than one measurement axis or, more generally, several degrees of freedom of the target can be determined (e.g. these can include orientation).

The signals induced in the sensors by the target are often quite small, and carefully designed and relatively expensive analog electronics is then required to filter and amplify these signals before they are used to determine the target position. When several sensors are used it is either necessary to use several channels of sensor circuitry – which adds to cost – or to multiplex the sensors to one channel of sensor circuitry – which increases the time for a measurement and therefore decreases the bandwidth or update rate of the system.

Invention

Our invention involves transmitting magnetic fields on a multiplicity of coils, so as to induce signals in the target, which vary with time in a manner that depends on the target's position. The signal in the target can either be sensed directly or via inductive coupling to a single sensor coil.

This provides a range of benefits:

- **Reduced levels of electro-magnetic noise** emitted by the system compared to known techniques. This is a particularly strong advantage since emissions are an increasingly stringent part of the approvals process for products in which the invention may be used. It is generally accepted by those skilled in the art that it is easier to cope with susceptibility (e.g. by electro-magnetic screening etc.) than it is to cope with emissions.
- **Cost and/or simplicity**: relatively cheap, digital electronics can be used to drive the transmit coils. At most one set of analog electronics is required for the sensor coil. Also, it is easier to measure the timing of the sensor signal using simple electronics than the amplitude of the sensor signal, which is often used in the prior art. This is a key advantage when one considers the development costs and risks associated with the development of an application specific integrated circuit (ASIC). Such developments are notoriously expensive, difficult and risky – particularly those involving analogue measurements or processing. This invention tends to reduce the cost and risk associated with ASIC development by employing predominantly digital techniques which are easier and quicker to develop.
- **Bandwidth:** because the sensor signal can be processed in real time with simple circuitry, without the need for a microprocessor for example (i.e. simple discrete electronic componentry may be used), high bandwidths can be achieved. In addition, multiple measurements can easily be made in parallel, e.g. measurements at more than one spatial scale or measurements of more than one degree of freedom of the target.

Embodiments

In the first embodiment, the target moves along a one-dimensional path (e.g. linear, circular, curvi-linear); let x denote the position of the target along this path. Two transmit coils extend along the measurement path; let C1(x) and C2(x) denote the coupling between the respective coils and the target at a position x when a unit current is passed through the coils. The coils are arranged so that this coupling varies with x like

$$C1(x) = A.\cos(2\pi x/\lambda), \qquad C2(x) = A.\sin(2\pi x/\lambda),$$

where λ is a fixed "wavelength" and A is an amplitude that does not depend on x.

Sensor coils with coupling functions of this form are well known in the prior art (e.g. resolvers, Sensus wheel encoder etc.).

Consider driving the first transmit coil with a time varying signal of the form $\cos(\omega 0.t).\cos(\omega 1.t)$ and driving the second transmit coil with a time varying signal of the form $\cos(\omega 0.t).\sin(\omega 1.t)$. The total signal induced in the target by these two transmit signals is

$$C1(x).\cos(\omega 0.t).\cos(\omega 1.t) + C2(x).\cos(\omega 0.t).\sin(\omega 1.t)$$
$$= A\cos(\omega 0.t)[\cos(\omega 1.t).\cos(2\pi x/\lambda) + \sin(\omega 1.t)\sin(2\pi x/\lambda)].$$
$$= A\cos(\omega 0.t).\cos(\omega 1.t - 2\pi x/\lambda)$$

This signal has a carrier frequency of $f0=\omega 0/2\pi$ plus an amplitude modulation of $\cos(\omega 1.t-2\pi x/\lambda)$. The carrier can be demodulated using synchronous detection and low pass filtering, leaving a signal that varies like $\cos(\omega 1.t-2\pi x/\lambda)$. This signal varies periodically with frequency $f1=\omega 1/2\pi$ with a phase shift that depends linearly on x. As is well known, simple digital electronics (e.g. a comparator, edge detectors, logic gates) can be used to convert this signal into a pulse width modulated (PWM) signal with frequency f1 and duty ratio then varies linearly with x. Note that the frequency f1 is the update rate of the system – the position x is determined during each cycle of this frequency.

It is helpful to consider the modulating field as rotating field which rotates in space as it travels along the measurement path.

Some details of this embodiment:

- If the target signal is sensed directly (e.g. the target is a coil connected to sensing electronics) then the carrier frequency f0 can be 0. In general, the system measures frequencies in the range [f0-f1,f0+f1] and it is often advantageous to use a large value of f0 to avoid interference from low frequency noise and other sources of inductive signals (e.g. mains voltages at 50/60Hz and their harmonics).
- If the target is sensed indirectly, then a suitable embodiment is for the target to be a magnetically sensitive resonator (e.g. a LC resonator, a coil attached to a quartz or crystal resonator, a magneto-mechanical resonator) with f0 set to the resonant frequency of the target. The modulation frequency f1 should lie within the response bandwidth of the resonator, i.e. if the resonator has a quality factor of Q then f1 should be significantly less than f0/Q.
- If f1 is greater than f0/Q the resonator will simply not respond significantly to the modulation.
- If f1 is comparable to f0/Q the resonator will respond but with some phase delay which will add some offset to the position measurement (because the position x is inferred from the phase of the f1 modulation). For example; if f1=.1f0/Q then the phase offset is ~10°; if f1=0.01f0/Q then the phase offset is ~1°.
- Both the resonant frequency f0 and the Q factor will depend on the electrical properties of the resonator, which in turn depend on temperature. The sensitivity of the phase offset at f1 to these effects decreases the smaller the quantity (f1.Q)/f0 becomes, i.e. decreasing f1 or Q helps.
- One method for compensating for the phase offset is to make two measurements, with the polarity of the second coil reversed between the measurements; the polarity of the position-dependent phase shift will reverse, but the polarity of the phase offset due to the resonator response will remain the same, allowing the two phases to be separately determined.

As is well known, multiple resonant targets with different resonant frequencies can be tracked independently.

It is important that the phase of the f0 carrier is essentially identical in the two transmit coils, as otherwise this induces a phase shift in the f1 modulation which is interpreted as a position error (this happens because the gain of the synchronous detector is sensitive to the phase of the f0 signal).

Other embodiments:

- In the first embodiment, a single degree of freedom – the position x – was determined from the phase of the modulation at frequency f1. Now, the modulation wave in this case is sinusoidal and its phase can be determined from the timing of one of its zero crossings, say the one with positive slope. The other zero crossing is always separated from this one by a phase difference of π. If a third transmit coil is used, transmitting at a frequency 2f1, then this phase difference will also depend on the target position. The phase of the two zero crossings can therefore be used to determine independent degrees of freedom of the target, e.g. linear position in two orthogonal axes, linear position along one axis and one angle of orientation of the target with respect to that axis, etc. Note that this still only involves timing measurements on the target signal, and that the two measurements can be made at the same bandwidth as in the first embodiment.
- The target position can be measured along more than one axis simultaneously by using a pair of coils as described in the first embodiment for each axis, with the same carrier frequency for all the coils but with the modulation frequency used differing between the pairs of coils. All the pairs of coils transmit simultaneously. The target signal, whether received directly or via inductive coupling, can be filtered, amplified and synchronously detected at the carrier frequency using one set of sensor electronics and the demodulated signal will contain phase shifted signals at each of the modulation frequencies. The phase shift at each modulation frequency can be determined by a set of bandpass filters to isolate each frequency plus the usual digital electronics to derive a phase-related signal, or by digitising the demodulated signal and using FFT methods. The FFT method is particularly simple if the modulation frequencies are all multiples of a common base frequency. The phase shift at each demodulation frequency can be used to infer the position of the target along the corresponding axis.
- In the first embodiment, the modulating signals were both sinusoidal. This isn't strictly necessary and it is often to use modulating signals that can be easily using simple electronics. For example, the modulating signals could be triangular waveforms. The phase of the modulation can be decoded in the usual way by only looking at the fundamental frequency of the modulated signals, i.e. by filtering out the higher harmonics present in the triangular waveform. Alternatively, if no filtering is used the zero crossing point of the demodulated waveform will vary with the target position in some predictable but non-linear manner which could, if desired, be converted to a linear measurement of position by a look-up table or similar technique.

- In order to minimise the system's susceptibility to noise an additional receive coil may be added in order to balance the first receive coil.

Although it is helpful to consider this invention as a position sensor it should also be noted that the invention may be used to detect other environmental factors. For example in the instance where the target is a resonant circuit containing a coil, capacitor and resistor such a configuration may be used to measure temperature, humidity, fluid conductivity etc. Since resistance or capacitance are notoriously sensitive to temperature and humidity, the effects of changes in such parameters may be sensed by a change in the qualities of the target, for example, a shift in the target's resonant frequency may be determined by using multiple interrogation frequencies. Such changes may be further enhanced by suitable selection of the target's components e.g. the use of a thermistor or capacitors of known variable qualities. The characteristics of fluid conductivity may also be used to make or break parts of the resonant circuit - hence enabling or disabling the resonant qualities of the target. One such useful application might be in determination of water quality in washing machines or dishwashers. Another example application where change in capacitor values is the determination of humidity in the exhaust of a clothes dryer, where it is useful to optimise drying cycles.